Interim Progress Report No. 7

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Case Inst. Tech.

The present progress report letter covers work performed in the period January, 1965 - June 30, 1965. In the past six months the following reports have been completed:

D. E. Loper	A-31	An Analysis of Confined Vortex Flows
G. A. Otteni	A-35	A Study of the Theory and Measurement of Plasma Diffusion
D. E. Loper	A-37	An Analysis of Confined Magnetohydrodynamic Vortex Flows
M. R. Smith W. B. Johnson	A-38	A Measurement of Energetic Test Electrons Interaction With a Plasma
M. R. Smith	A-39	Collisional Interaction of Energetic Test Electrons With a Plasma

The following papers have either been published or submitted for publication:

B. S. Tanenbaum "Fields Produced by a Current Source in a Partly Ionized Gas". J. Appl. Phys. 36, 1288 (1965).

M. R. Smith "A Measurement of Energetic Test Electrons Interaction With a Plasma". Phys. Rev. Letters (sent July 2, 1965).

R. M. Scott & M. R. Smith "A Note on Commercial Spectral Sources for Instrumental Resolution Measurements". Rev. Sci. Inst. (sent June 28, 1965).

O. K. Mawardi "The Use of Langmuir Probes for Low Density Plasma Diagnostics". Am. J. Phys. (To appear soon).

Twenty five (25) copies of all the above mentioned publications will be mailed under separate cover to NASA Headquarters as they become available.

The past period has seen an intensification of our activities in laser work and in the general area of microwave interactions with plasmas.

Reports on specific problems are outlined below.

I. Measurement of Cyclotron Radiation in a Plasma

(A. M. Ferendeci, O. K. Mawardi, R. O. Shaffner and A. Alper)

The wide-band radiometer referred to in our Progress Letter #6 is still being built. The ridge type wave guides and associated components to cover the 3-11 kmc. range has been completed. Preliminary testing of the 30 mc. low noise I.F. amplifier with part of the guides in place indicate satisfactory operation. The ridge-wave guide switch for power comparison is still not finished and is the last component required for the completion of the radiometer.

On the theoretical side, an attempt is made to estimate the effect of the wave-guide walls on the power radiated by the electrons at the cyclotron frequency and at its harmonics.

II. Energy Loss of Electrons Traversing a Plasma

(W. B. Johnson, M. R. Smith)

The experimental determination of the distribution of energy losses by a beam of energetic test electrons traversing a dense high temperature plasma and described in part in our Progress Letter #6 has been completed. In the experiment the test electrons used have an energy of 3000 electron volts and the plasma density varies from 5×10^{15} to 1×10^{16} cm^{-3} at a temperature of 40,000 K. A collisional theory developed through the hoc extension of the maximum impact parameter $P_{max} = \lambda_D \frac{w}{w_t}$ where λ_D is the Debye length, w the plasma energy and w_t the test electron energy yields theoretical results which is in substantial agreement with the calculations of various authors. The experimental findings, however, yield an average energy loss larger than the theoretical prediction. The experimentally found average energy loss and spread in the energy vary proportionally to the plasma electron density. A tentative energy gain mechanism has been proposed to explain this discrepancy between theory and experiment.

Both of the theoretical and experimental findings have been described in two reports (A-38 and A-39).

III. Magnetically Confined Plasma Beams

(R.E. Collin, D. A. Meskan, B. S. Tanenbaum)

The hot cathode glow-discharge experiment referred to in our Progress Letter #6 is now well under way. Ion waves have been excited in the discharge by means of a grid modulated at audio frequencies. The onset and production of these waves have been detected by means of movable Langmuir probes and spectroscopically using a monochrometer. In conjunction with the above diagnostic methods phase sensitive correlation detectors have been employed to measure phase shifts and amplitudes of the waves. Preliminary measurements set the wave length of these waves at 10 cm for frequencies of the order of 12 kilocycles and velocities of the order of 10^5 cm/sec.

IV. Microwave Ionization and Heating of a Plasma

(A. M. Ferendeci, O. K. Mawardi, F. J. Mayer)

The ionization and heating experiments by microwave have proceeded very well. The procedure has been now highly refined. An x-band magnetron pulse of 250 kw peak power is applied to a microwave cavity in which the gas container is located. A subsequent pulse from an S-band magnetron of 1 Mw peak power of the same duration is used to further ionize the gas and heat the plasma which has a volume of 300 cm^3 approximately.

Since the very high microwave power that is used in this experiment introduces important non-linear effects which are normally neglected in small signal theory, an attempt has been started to predict the depth of penetration, the loss mechanism and the rate of ionization as a function of time by means of semi-empirical calculations. In these calculations consider non-linearity has been incorporated in the governing equations and an effective conductivity is obtained.

In order to measure the rate of production of electrons in the cavity a microwave interferometer has been built. In conjunction with the interferometer a laser beating technique as described in Section 5 of this letter will be used.

A method for sampling the shift of the resonance frequency in a cavity has also been developed in conjunction with this work. The sampling time, the sampling rate and the length of the total sampling time being variable this technique allows a single oscilloscope trace to display the dependence of the electron density and the recombination time on the time inside the cavity.

A paper now in preparation will summarize some of these findings.

V. Laser Investigations

(W. B. Johnson, H. J. Cook, T. P. Sosnowski)

A technique has been developed to measure low electron densities in the 10^{10} - 10^{12} electrons per cm^3 by using lasers. In this method the beat frequency between two lasers is used to estimate the required density. One of the lasers is used as the standard while the other has its cavity perturbed by the introduction in it of the plasma whose electron density needs to be obtained. Expressions for the difference frequency as a function of laser wave length and plasma electron density have been derived. Special precautions to minimize problems due to vibration and thermal effects of the laser mirror mounts had to be taken. These and some typical experimental results are described in a paper now in preparation.

VI. Character of Switch-on Shock Waves

(W. B. Johnson, G. L. Spencer)

The discharge time of the condenser bank reported in our Progress Letter #5 has been lengthened to 2 μsec. instead of the previous figure of 1/2 μsec. in order to improve the driving pressure on the shock wave. Spectroscopic measurements of the temperature of the plasma after preionization indicate that the state of the plasma is reasonably quiescent and that it is about 80% ionized. The shock velocities that have been observed are of the order of 2.5 cm/μsec. Preliminary observations indicate that the luminous front is coincident with the jump of the magnetic field and that this jump is of the order of 20% of the applied axial bias. It was also found that the strength of the jump qualitatively agrees with classical MHD theory.

VII. Ambipolar Diffusion

(R. E. Collin, O. K. Mawardi, G. A. Otteni)

The initial phase of this project has been completed. A theoretical treatment of the diffusion of an electron cloud in various bounded configurations has been developed. In the treatment, dyadic diffusion coefficients have been used so that diffusion in the presence of magnetic fields can be included. In the theoretical derivation attachment, ionization and diffusion to the walls are the only mechanisms considered in the conservation relation for the number of electrons in the plasma. Solutions for the plasma density distribution have been obtained for rectangular and cylindrical geometries and these theoretical predictions have been compared with experimental findings. In the experiment (previously described in Progress Letters #4 and 6) the plasma density is measured by the reflection of the dominant TE_{10} rectangular mode from the decaying plasma distribution. A number of resonances in the plasma are detected and tentative explanations for these resonances are discussed.

A report describing these findings has been completed

VIII. MHD Induction Generation

(S. Ostrach, D. E. Loper)

An analysis has been completed to describe the swirling (vortex) flow (with a net radial mass flow) of a viscous electrically-conducting fluid confined between two finite parallel flat plates in the presence of an applied axial magnetic field.

Of primary concern were the details of the flow velocity field including the blockage of the vortex motion by the buildup of boundary layers on the end plates and of the redistribution of radial mass flow into these boundary layers. The main assumptions were that the fluid be incompressible with constant properties and that the flow be laminar, steady, and axisymmetric. The analysis is also limited to the case of the confining end plates close together compared with their radius.

The resulting profiles are discussed as functions of the primary parameter, the radial mass flow, and, where possible, are compared with previous work. It is shown that for estimation of the boundary-layer blockage a non-magnetic analysis will provide an upper bound on the boundary-layer thickness for the corresponding magnetic problem. That is, for a given set of conditions, the boundary-layer blockage is maximum for the non-magnetic case.

The dependence of the radial velocity on the various parameters was analyzed to determine how these parameters affect the redistribution of radial mass flow. It was found that the radial mass flow in the boundary layers is largest for the non-magnetic cases. As magnetic effects are added, the boundary-layer mass flow decreases, lessening the tendency for radial backflow (reversal of radial velocity outside the boundary layers) to occur.

With regard to the temperature distribution it was found that if the Prandtl number is of order one, the boundary layers can be cooled without affecting the main fluid temperature. This effect is important if it is desired to quench the boundary layers to decrease wasteful loop currents.

This work has been prepared as a Ph.D. Thesis entitled, "An Analysis of Confined Magnetohydrodynamic Vortex Flows" by David E. Loper. A version of this work is being prepared for publication in a journal.